Development Specification for the Feedwater Supply Assembly (FSA), FSA-431 with Integrated Auxiliary Feedwater Supply Assembly (AFSA), FSA-531

Engineering Directorate
Crew and Thermal Systems Division

Verify this is the correct version before use

Date: October 18, 2017
Revision: N/C
CTSD-ADV-1112

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Engineering Directorate
Crew and Thermal Systems Division
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Development Specification for the Feedwater Supply Assembly (FSA), FSA-431 with Integrated Auxiliary Feedwater Supply Assembly (AFSA), FSA-531

Ian Anchondo
FSA Component Lead

Colin Campbell
PLSS Development Team Lead

REVISIONS			
DATE	AUTHOR	DESCRIPTION	REV. LETTER
6/23/2017	I. Anchondo	Initial Release	N/C

TABLE OF CONTENTS

Section **Page**

TABLE OF FIGURES

TABLE OF TABLES

1.0 INTRODUCTION

1.1 SCOPE

The FSA with Integrated Aux FSA Specification establishes the requirements for design, performance, and testing of the FSA-431/FSA-531 assembly in compliance with CTSD-ADV-780, Development Specification for the Advanced EMU (AEMU) Portable Life Support System (PLSS).

1.2 CONVENTIONS AND NOTATIONS

1.2.1 RATIONALE

A rationale statement is included for each requirement. The purpose of the rationale statement is to indicate why the requirement is needed, the basis for its inclusion in a requirements document, and to provide context and examples to stakeholders. It is important to note that a rationale is not binding, and it only provides supporting information. In the event there is an inconsistency between the requirement and the rationale, the requirement is binding and takes precedence.

1.2.2 DESIGNATIONS AND PRIORITIZATION

The convention used in this document to indicate requirements, goals, and statements of fact is as follows:

Designation	Description
“Shall”	used to indicate a requirement which must be implemented and its implementation verified
“Should”	used to indicate a goal which must be addressed by the design but is not formally verified
“Will”	used to indicate a statement of fact and is not verified

2.0 DOCUMENTS

The documents listed in this section represent the documents that have been identified either in part or in whole within this document.

2.1 APPLICABLE DOCUMENTS

The applicable documents are documents that have been explicitly identified within requirements statements (i.e., “shall” statements) and invoked as technical requirements for implementation. Each requirement statement identifies the applicable subsections of a document unless it has been deemed appropriate to invoke the entire document.

ASTM D6193	Standard Practice for Stitches and Seams
JPR 5322.1	Contamination Control Requirements
NASA-STD-6016A	Standard Materials and Processes Requirements for Spacecraft
NASA-STD-6001B w/CHANGE 2:	Flammability, Odor, Off-gassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

2.2 REFERENCE DOCUMENTS

Documents that are identified but are not invoked within requirements statements are listed below.

3.0 FEEDWATER SUPPLY ASSEMBLY (FSA) FSA-431/AUX FSA FSA-531

This section contains the technical design and performance requirements for the integrated assembly of the Feedwater Supply Assembly and Auxiliary Feedwater Supply Assembly for the Advanced EVA Development Portable Life Support Subsystem (PLSS).

3.1 FSA DESCRIPTION

Although the integrated FSA will be located within the Space Suit Assembly (SSA), its function is integral in the performance of Portable Life Support functions:

FSA-431

- Stores feedwater used to provide makeup water to the thermal loop as it is consumed by the SWME, HX-440 in the evaporative cooling process
- Material compliancy allows suit pressure to provide pressurization of the thermal control loop at the pump inlet.
- Provides low level detection to enable a controlled EVA termination without the reliance of redundant systems under most operations concepts

FSA-531

- Stores feedwater used to provide makeup water to the thermal loop as it is consumed by the HX-550.
- Material compliancy allows suit pressure to provide pressurization of the thermal control loop at the pump inlet.

3.2 PERFORMANCE REQUIREMENTS

3.2.1 LIFE PERFORMANCE

3.2.1.1 [R.FSA.001] OPERATIONAL FILL/DRAIN CYCLES

The FSA shall have an operating life as specified in Table 3.2.1.1.-1:

Component	Function	Cycles (minimum)	Minimum Duration (hrs)
Pressure Cycle	Fill*/Drain Cycles *Fill to MEOP	400[1,2]	---

Table 3.2.1.1-1 – Operating Life

Rationale: The goal is to make the hardware and its associated certification "robust-enough" such that detailed tracking of operating cycles and the resultant operational over-head is not required.

(1) This is based on one cycle per EVA for 100 EVAs and a scatter factor of 4 as derived from operational concepts covered in CTSD-ADV-959.

(2) A cycle is defined as the process of going from a discharged state (ullage volume remaining) to a fully charged state at MEOP and then back to a discharged state (ullage volume remaining).

(3) Although the number of cycles really only applies to the FSA-431 component of the integrated assembly, it makes little sense to reduce the number for FSA-531 which will be of similar construction and will need to demonstrate robustness as it is a redundant life support system component.

3.2.1.2 [R.FSA.002] USEFUL LIFE

The FSA shall have a useful life of 5 years minimum without refurbishment assuming that the usage rate does not exceed operational life (Para 3.2.1.1).

Rationale: This provides a tracking clock from the time wetted service is started and is considered the total "life time" from birthdate of the hardware.

3.2.1.3 [R.FSA.003] Shelf Life

The FSA shall have a shelf-life of 10 years minimum.

Rationale: This allows for program logistics flexibility without recertification.

3.2.2 Material Compatibility

3.2.2.1 [R.FSA.004] Feedwater

The FSA shall be compatible and operate using water per JSC-SPEC-C-20D, Grade B with the added contaminants totaling the amounts dictated in Table 3.2.3.5-1.

Contaminant	**Amount (mg/L)**
Barium	0.1
Calcium	1.0
Chlorine	5.0
Chromium	0.05
Copper	0.5
Iron	0.2
Lead	0.05
Magnesium	1.0
Manganese	0.05
Nickel	0.05
Nitrate	1.0
Potassium	5.0
Sulfate	5.0
Zinc	0.5
Organics	
Total Acids	0.5
Total Alcohols	0.5
Total Organic Carbon	0.3

Table 3.2.3.5-1 – PLSS Feedwater Contaminants

Rationale: The table was generated with margin based on the capabilities of the International Space Station Water Processor Assembly (WPA). The potable water requirements specified per SSP 41000, Table LVI convey the Spacecraft Maximum Allowable Concentrations (SMAC) that can be tolerated by a human for long durations whereas the included table seeks to require performance with water that includes contaminants reasonable to expect a spacecraft to deliver to the PLSS. This satisfies AEMU PTRS requirement, R1.311.

3.2.2.2 [R.FSA.005] Gaseous Nitrogen

The FSA shall be compatible and operate using gaseous nitrogen per MIL-PRF-27401F, Performance Specification for Propellant Pressurizing Agent, Nitrogen, Type I, Grade B as a test fluid.

Rationale: Gaseous nitrogen provides a safe testing fluid and will be used as a pressurant on the outside of the FSA bladder.

3.2.2.3 [R.FSA.006] GASEOUS OXYGEN

The FSA shall be compatible and operate using gaseous oxygen per MIL-PRF-27210G, Performance Specification for Oxygen, Aviators Breathing, Liquid and Gas, Type I as the working fluid.

Rationale: Gaseous oxygen is required for human metabolism; gaseous form storage of oxygen is the basis for the current PLSS design approach (CTSD-ADV-959). Gaseous oxygen will be used on the outside of the FSA bladder as a pressurant in the manned or flight configuration.

3.2.3 PHYSICAL CHARACTERISTICS

3.2.3.1 [R.FSA.007] FSA ASSEMBLY

The FSA shall be made up of modular bladders that can be connected or disconnected from the larger assembly.

Rationale: Different size bladders will make up the total FSA assembly and therefore will require the need to mix and match sizing to make up the total FSA mass.

3.2.3.2 [R.FSA.008] MODULAR BLADDERS

The FSA modular bladders shall have an inlet and outlet connection.

Rationale: The design should be able to purge water in and out to enable the sampling of water.

3.2.3.3 [R.FSA.009] RESTRAINT MATERIAL

Each modular bladder shall have an outer restraint material.

Rationale: FSA Prototyping has proven to benefit from a two-layer construction with the bladder withholding the water and the restraint up taking the pressure load. The aggregate will make up the FSA system.

3.2.3.4 [R.FSA.010]

The FSA shall have 10 Fill/Drain cycles prior to performing Acceptance Testing to ensure the stability bladder material to the restraint material.

Rationale: Prototype testing has shown the need to "break-in" the bladder before a steady-state volume of water is defined.

3.2.3.5 [R.FSA.011] MASS

The FSA shall have a total dry mass less than .23 kg [0.5 lbm].

Rationale: This is the basic allocation provided in the MEL.

3.2.3.6 [R.FSA.012] VOLUME – SHAPE FACTOR

The FSA modular bladders shall not exceed a width of more than 12 inches.

Rationale: The maximum width allocated in the suit currently is about 12 inches in width therefore cannot exceed in that dimension.

3.2.4 FEEDWATER CAPACITY

3.2.4.1 [R.FSA.013] FEEDWATER SUPPLY ASSEMBLY (FSA-431)

The FSA shall provide a minimum usable feedwater quantity of 4.5 kg [10 lbm].

Rationale: This number is currently in-flux based on Qmet, environmental heat leak, and avionics waste heat, but the range is well vetted with historical suit systems: Shuttle/ISS EMU = 9.2 lbs H2O in the combined primary and reserve feedwater tanks and Apollo EMU = 11.9 lbs H2O with the combined primary and auxiliary feedwater bladders on the -7 PLSS. This satisfies the intent of the AEMU PTRS requirement, R1.309.

3.2.4.2 [R.FSA.014] FSA-431 ULLAGE

The FSA-431 shall have an ullage below 5% of the mass per individual bladder.

Rationale: Overfilling the bladders to achieve the necessary usable water is not desired above 0.5 lb of the total mass.

3.2.4.3 [R.FSA.015] AUXILIARY FEEDWATER SUPPLY ASSEMBLY (FSA-531)

The FSA-531 shall provide a minimum usable auxiliary feedwater quantity of .45 kg [1 lbm].

Rationale: This number is based on the initial sizing for the auxiliary thermal loop documented in ESCG-4470-12-TEAN-DOC-0019. For this condition, with an allowable heat storage of 300 BTU, a thermally neutral environment (0 heat leak), an average metabolic rate of 1200 BTU/hr, a 2 acfm ventilation flowrate, and a 60 minute duration, the needed water quantity was .32 kg [0.7 lbm] of water.

Item	*Feedwater kg [lbm]*
Feedwater required for design point: o *1200 BTU/hr* o *60 minute retreat* o *Thermal environment: neutral* o *2 acfm flowrate*	*0.32 [0.7]*
LCVG water charge estimated for core only	*.14 [0.3]*
Total Usable:	*.45[1.0]*

This does not include the ullage quantity that varies with design of the FSA itself.

3.2.4.4 [R.FSA.016] FSA-531 ULLAGE

The FSA-531 shall have an ullage below 5% of the mass per individual bladder.

Rationale: Overfilling the bladders to achieve the necessary usable water is not desired above 0.5 lb of the total mass

3.2.5 PRESSURE PERFORMANCE

3.2.5.1 [R.FSA.017] PRESSURE SCHEDULE

The FSA shall have a pressure schedule as defined in Table 3.2.4-1.

Operating Pressure	**Pressure kPa (diff) [psid]**
Maximum Design Pressure (MDP) (2)	180 [26.1]
Proof Pressure (1.5 x MDP) (1)	270 [39.2]
Burst Pressure (2.5 x MDP) (1)	450 [65.3]

Table 3.2.4-1 – Pressure Schedule

Rationale:

(1) This satisfies Table 3.3.1-1 (Minimum Factors of Safety for Pressure) Sub para 3.D (Actuating cylinders, valve, etc.) in SSP 30559, ISS Structural Design and Verification Requirements.

(2) This represents the following pressure stack-up for the primary thermal loop (FSA-431) with the auxiliary thermal loop (FSA-531) sufficiently less in operation but benefitting from the robustness of the primary design:

Condition/Source	***Pressure***
Maximum charging pressure from vehicle with multiple levels of over-pressure protection	*15 psid*
Cabin reference pressure for the feedwater recharge supply	*15.2 psia*
Lowest suit pressure in which a vacuum feedwater recharge would be performed	*-4.3psia*
	31.1 psid
Maximum Design Pressure (MDP)	***25.9 psid***

3.2.6 Leak Detection

3.2.6.1 [R.FSA.018] Low Level Detection

The FSA shall be isolate 1.5 lb of water with a 0.5 psid +/-0.05 check valve.

Rationale: The need to discern the last 1.5 lb of cooling is necessary to determine an unexpected leak or a higher than expected metabolic load without the insight of Mission Control to provide insight.

3.2.7 FSA Construction

3.2.7.1 [R.FSA.019] Bladder Material

The FSA bladders shall be made from Teflon FEP or Flourel.

Rationale: Bladder materials interfacing with EMU Thermal Systems are either Teflon FEP or Flourel.

3.2.7.2 [R.FSA.020] Restraint Material

FSA Restraint shall be made of a breathable material with wicking capability.

Rationale: The restraint layer should not hold water to the level where microbial growth can occur in a closed humid environment.

3.2.8 Cleanliness

3.2.8.1 [R.FSA.021]Internal Cleanliness

The FSA shall meet Level 150A cleanliness as defined per JPR 5322.1G.

Rationale: Same cleanliness level as the rest of the loop.

3.2.8.2 [R.FSA.022]External Cleanliness

The FSA shall be clean to VC+UV as defined per JPR 5322.1G.

Rationale: Due to the potential of a wetted external surface, the presence of hydrocarbons shall be kept to a minimum to avoid microbial grown. UV provides a level of verification.

3.2.9 Passive Characteristics

3.2.9.1 [R.FSA.023] Gas Absorption/Permeation

The FSA shall limit the amount of gas that either enters or leaves the bladder volume to 5 sccm.

Rationale:

3.2.9.2 [R.FSA.024] Unpressurized Leakage

The FSA shall limit external leakage to 9.56E-11 kg/sec [7.59E-07 pph] maximum at a pressure of 29.6 kPa [4.3 psia] regardless of orientation.

Rationale: The FSA shall not leak during EVA or quiescent operations.

3.3 INTERFACE REQUIREMENTS

3.3.1 Structural

3.3.1.1 [R.FSA.025] Suit Interface

The FSA shall have the necessary attachment to allow for hard mount to the suit hatch volume.

Rationale: Although undefined the FSA assembly will be attached to the suit volume attached to the hatch space.

3.3.2 Crew/Human Factors

3.3.2.1 [R.FSA.026] Sharp Edge Limits

The FSA should comply with the Corners and Edges limits established in Table 3.3.2.5-1.

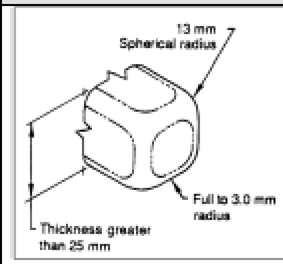
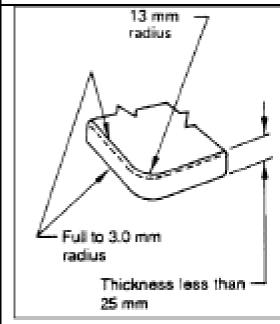
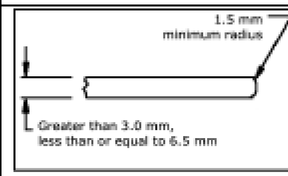
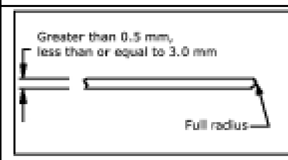
Material Thickness, t	Minimum Corner Radius	Minimum Edge Radius	Figure
t > 25 mm (t > 1 in)	13 mm (0.5 in (spherical))	3.0 mm (0.125 in).	
6.5 mm < t ≤ 25 mm (0.25 in. < t ≤ 1 in.)	13 mm (0.5 in.)	3.0 mm (0.125 in.)	
3.0 mm < t ≤ 6.5 mm (0.125 in. < t ≤ 0.25 in.)	6.5 mm 0.25 in.	1.5 mm (0.06 in.)	
0.5 mm < t ≤ 3.0 mm (0.02 in. < t ≤ 0.125 in.)	6.5 mm 0.25 in.	Full radius	

Table 3.3.2.5-1 – Corners and Edges

Rationale: The NASA-STD-3001, Vol II, [V2 9009], Sharp Corners and Edges – Fixed requires this for Crew interfaces.

3.4 MAINTAINABILITY

3.4.1 INTERCHANGEABILITY

3.4.1.1 [R.FSA.027] MODULAR BLADDER INTERCHANGEABILITY

The FSA shall be interchangeable with any other unit of the same part number.

Rationale: The definition as provided in JSC EA-WI-027 is as follows:
Two or more parts are interchangeable when they possess such physical and functional characteristics as to be equivalent in performance and durability, and are capable of being exchanged one for another without alteration of the items themselves or adjoining items. Functional and physical characteristics, which would constitute interchangeability, are:

- *Parts must have the same design envelope and have no limitations imposed on use.*

- *Parts must utilize the same attachments, mountings or mating surfaces. Attachments, connectors, wiring, ground support equipment, and tubing must be the same to the extent that no re-work is required on installation.*
- *Parts must meet all baselined design requirements for performance and durability. Performance or durability design requirements include the same safety, strength, electrical, mechanical, reliability, maintainability, tolerance, and weight and center of gravity requirements.*
- *Parts must have the same adjustments, testing, operations, and maintenance requirements and design to the extent that the same test procedures, specifications, and operating procedures have been and/or may be utilized.*

3.5 INDUCED ENVIRONMENTS

3.5.1 ENVIRONMENT COMPATIBILITY

3.5.1.1 [R.FSA.028] FLAMMABILITY

The FSA shall meet flammability standards as specified in NASA-STD-6001, *Flammability, Odor, Off-gassing and Compatibility Requirements and Test Procedures for Materials in Environments that support Combustion*.

3.5.1.2 [R.FSA.029] TOXIC OFF-GASSING

The FSA shall not have any toxic off-gassing as specified in NASA-STD-6001, *Flammability, Odor, Off-gassing and Compatibility Requirements and Test Procedures for Materials in Environments that support Combustion*.

3.5.2 PRESSURE

3.5.2.1 [R.FSA.030] AMBIENT PRESSURE

The FSA shall operate in a pressure environment ranging from 3.5 psia to 23.1 psia.

3.5.2.2 [R.FSA.031] AMBIENT PRESSURE - LAUNCH

The FSa, in a stowed configuration, shall operate after exposure to a pressure environment ranging from 0.0 to 130 kPa [0.0 to 18.8 psia].

3.5.3 [R.FSA.032]

3.5.4 [R.FSA.033] HUMIDITY

The FSA shall operate in an environment with Relative Humidity (RH) cycling between 30 $\pm$ 10% and 80 $\pm$ 10% for ten 24 hr cycles per MIL-STD-810G, Method 507.5, Induced Cycle B3.

3.5.5 [R.FSA.034] GRAVITATIONAL FIELDS

The FSA shall operate in the gravitational fields defined in Table 5.1.4-1 in any orientation.

Environment	Gravity Field (g)
Terrestrial	1
Lunar	0.17
Mars	0.38
LEO	~0

Table 5.1.4-1 – Gravitational Fields

Rationale: The PLSS must perform in a variety of gravity fields to meet system performance requirements across all of the applicable environments. This satisfies the intent of AEMU PTRS requirements, R1.016 and R1.017.

3.5.6 [R.FSA.034] DYNAMIC LOADS

Reference CTSD-ADV-780, Para 5.1.5.

ACRONYMS AND ABBREVIATIONS

CTSD	Crew and Thermal Systems Division
EMU	Extravehicular Mobility Unit
EV	Extra-Vehicular
EVA	Extravehicular Activity
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
ISS	International Space Station
IV	Intra-Vehicular
IVA	Intra-Vehicular Activity
JSC	Johnson Space Center
KOZ	Keep Out Zone
MEOP	Maximum Expected Operating Pressure
NASA	National Aeronautics and Space Administration
PLSS	Primary Life Support System or Portable Life Support System
PPRV	Positive Pressure Relief Valve
RH	Relative Humidity
SSA	Space Suit Assembly
TBD	To Be Defined

DEFINITIONS

STP	Standard Temperature and Pressure (STP) The STP reference for all mass-referenced volumetric flows discussed here-in shall be that as defined by the National Institute of Standards and Technology (NIST) Pressure = 1 atm = 14.676 psia = 101.325kPa Temperature = 0C = 273.15K = 32F